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THE SCOPE OF BLAST AND SHOCK BIOLOGY AND PROBLEM AREAS IN RELATING PHYSICAL AND BIOLOGICAL PARAMETERS

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PREFACE

The material presented in this report was selectively summarized as an introduction (a) to a briefing by six other Lovelace Foundation personnel before the Committee on Hearing, Bioacoustics and Biomechanics of the National Academy of Sciences — National Research Council in Washington, D. C. on October 6, 1966 and (b) to a Session on the Sensitivity of Personnel presented before the New York Academy of Sciences in New York City on October 11, 1966 during the Conference on Prevention of and Protection Against Accidental Explosions of Munitions, Fuels and Other Hazardous Mixtures.

The data are of interest to those who would understand the nature of blast and shock biology, appreciate the physical and biomedical problem areas involved and grasp the quantitative relations on which the available, but tentative biomedical criteria for assessing blast-related hazards are based.

The tentative criteria are useful to a wide variety of safety officers and engineers including those at missile and satellite launch sites; industrial concerns manufacturing, handling, transporting, storing and using explosives; they are applicable in industrial medicine, in protective design and construction, and in planning appropriate contributions to environmental health and control.

Limitations include those encompassed when extrapolations from animal to human responses are made, and when lack of information in many areas introduces constraints and uncertainties that will lessen only with improvements in the "state of the art" as well as in the conceptual understanding brought to bear.

The present study is a part of a continuous program of research which has been under way since 1952 aimed at better understanding human response to all the environmental variations associated with explosive events.

ABSTRACT

A few introductory remarks were followed by a brief discussion of the nature of hazards from air blast noting those due (a) directly to variations in pressure and (b) indirectly to the impact of penetrating and nonpenetrating, blast-energized missiles and the consequences of whole body displacement due to blast-induced winds or ground shock. The need for developing biomedical criteria based upon critical and measurable biological responses following exposure to significant and monitorable physical parameters was discussed in relation to hazards assessment. Also the multifaceted problem of tying up such information with blast-induced variations in the environment that occur free-field and under various conditions of exposure was noted and emphasized.

ACKNOWLEDGMENTS

Appreciation is expressed to Dr. D. R. Richmond, Dr. E. G. Damon, Mr. I. G. Bowen and Dr. E. R. Fletcher for the use of some of their data and for fruitful discussions regarding the concepts presented in this report. Also, the author is indebted to Mr. I. G. Bowen for help in formulating Tables 1 and 2; to Mr. Robert A. Smith and Mrs. Violet Paulikonis for preparing the illustrative material; and to Mrs. Ruth P. Lloyd and Mrs. Martha E. Mitchell for editorial aid, for typing the many rough and final drafts of the manuscript, and with the help of Mrs. Virginia D. Carleno for proofreading the text.

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I. Introduction

To supplement earlier work,[1-16] substantial progress over the past fifteen years has been made to broaden understanding those physical, biophysical, and biological phenomena that are critical for better assessing air-blast hazards in man.[16-45] This has included noting the nature and scope of blast biology,[3, 9, 10-14, 17-22, 36, 39] attempting to set forth the physically and biologically oriented problem areas involved,[11, 26, 27, 28, 30-35, 37] formulating tentative biomedical criteria of relevance to blast-induced environmental variations,[2, 3, 14, 15, 16, 18, 21-23, 25, 29, 32-38] and utilizing such concepts to help define areas of potential risk near explosions varying widely in yield.[18, 21, 22, 30, 32, 34] Progress has required periodic review and the incorporation of new data as empirical and theoretical work progressed, technology improved, and additional disciplines were brought to bear.

Such a review, stimulated by the desire to make updated information available in one publication about the sensitivity of personnel should they be exposed close to detonating materials, has been under way for some time. The purpose of this presentation, a prelude and introduction to several relevant contributions in specialized areas by others,* is threefold as follows: first, to categorize blast injuries seen in animals and man; second, to delineate the problem areas that must concern those who would improve and broaden the understanding of biological blast effects; and third, to emphasize the need and requirements for developing criteria for evaluating hazards that are quantitatively as well as qualitatively sound.

II. Scope of Blast Biology

Air-blast injuries, mostly due directly or indirectly to the pressure pulse and high-velocity winds emanating from an explosive source, have been completely categorized by Zuckerman.[3] Though a less logical division into primary, secondary, tertiary and miscellaneous effects has been employed,[19, 21, 22, 28, 32, 34, 36, 38] the classification followed here is that simplified by Glasstone[18] to include direct and indirect effects.

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*See Preface.

A. Direct (Primary)

Direct or primary effects are those associated with blast-induced variations in environmental pressure. Under certain circumstances, the incident as well as the reflected and dynamic pressures contribute critically. Currently, it is known that the mammal is extraordinarily sensitive to the magnitude, rate, and character of the pressure rise and fall. The duration of the pulse, the ambient pressure at which exposure occurs, and animal size, type and age are also all significant variables, though little as yet is known quantitatively about the influence of age. Many more data about the response to typical or near typical wave forms are at hand than is the case for atypical pulses. However, tolerance is minimal for "fast"-rising, "long"-duration wave forms and maximal for those that from arrival rise "slowly" to their peak pressure.

Primary blast pathology — characteristically seen at those locations where variations in tissue density are the greatest, with the air-containing organs being the most susceptible, but also noted in many organs as a result of vascular air emboli arising in the lungs — is very much due to the violent inward implosion of the body wall along with the internal pressure variations that follow. The characteristically steep lethality-time curves noted in animals exposed at pressures that significantly depress survival,[29, 34, 36] are apparently due to air-embolic insult to the heart or central nervous system, or to cardiopulmonary embarrassment subsequent to post-exposure hemorrhage and edema (swelling) of the lungs.[12-14, 17, 21, 24, 34] Subsequent events often include abdominal inflammation, particularly severe if perforation of a hollow organ has occurred;[13, 39] pneumonia and loss of respiratory reserve due to rupture of the small air sacs (alveoli) of the lungs and to the characteristic patchy fibrosis (scarring) that has been noted in recent studies;[39] and other morbidity associated with long-term, air embolic circulatory and tissue damage, now known to be significant in the case of the kidneys and the heart and perhaps for other body organs as well.[46]

The early demise of nonsurvivors and the lack of impressively effective therapy for the severely injured,[5-7, 24] highlight not only the importance of protective and preventive measures and procedures, but emphasize the need for thoroughly understanding the etiologic mechanisms at play. Until this is forthcoming in all detail, one cannot know whether an enlightened approach to therapy and prophylaxis is or is not possible.

Because of the highly hazardous nature of primary blast lesions, an assessment of human tolerance must depend mostly upon animal studies and whatever information about man can be gleaned from accidental[10, 20] and war-time exposures,[5-8, 14, 18, 34, 41] circumstances that leave much to be desired from the quantitative point of view. Thus, the intraspecies scaling problems are of great importance and, if through future empirical and theoretical studies they can be solved, a satisfying precision in predicting human tolerance may well be forthcoming. *

B. Indirect Blast Effects

Indirect blast effects include first, injuries associated with the impact of penetrating or nonpenetrating missiles; second, damage that occurs as a consequence of whole-body displacement; and third, hazards in a miscellaneous category.

1. Missiles (Secondary Effects)

Injuries, due to the impact of missiles arising from the case of a detonating device or from the nearby environment as debris energized by blast pressures, winds, ground shock, and sometimes gravity, depend upon a number of factors. Among them are the mass, velocity, character, density, and angle of impact of the missiles; whether or not penetration or perforation occurs; the area and organ of the body involved; the amount and kind of clothing if any; and the immunological status and general health condition of the injured individual. The great deal of work done in wound ballistics[40] aids understanding damage in the case of penetrating wounds, but much more needs be known about the wounding power of both penetrating and nonpenetrating missiles, particularly those much larger than conventional projectiles and traveling at relatively lower velocities. The number and seriousness of the injuries caused by flying debris noted following the accidental explosions at Texas City[10,20] amply illustrate the importance of learning much more about the physical and biological factors at play.

2. Whole-Body Displacement (Tertiary Effects)

Damage, occurring as a consequence of gross translation of the body induced mostly by blast pressures and winds, but with ground shock, gravity, and a blow from a large missile often contributing, can be accelerative or decelerative in character. Either may be serious, but abrupt decelerative trauma is characteristically associated with high and early lethality.[25] Significant factors include the velocity change at impact, the time and distance over which deceleration occurs, the character and nature of the decelerating surface and the area of the body involved. Though trauma to the head is known to be highly hazardous, it is likely that blunt blows over the liver and spleen and other portions of the abdominal wall may also be quite dangerous at relatively low impact velocities. Here, for reasons similar to those noted for primary blast, quantitative evaluations will have to rely heavily on animal studies supplemented by careful analysis of human accidents and upon cautious experiments involving man. **

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*Note the contributions to appear as DASA-1857 by I. G. Bowen et al. and DASA-1860 by D. R. Richmond et al., which papers will also be published in the Proceedings of the New York Academy of Sciences Conference on Prevention of and Protection Against Accidental Explosion of Munitions, Fuels and Other Hazardous Mixtures, New York, October 10-13, 1966.

**See contribution by C.-J. Clemedson, appearing in the proceedings of the conference mentioned above.

3. Miscellaneous Effects

Miscellaneous blast effects include those due to dust,[15,36] thermal damage such as flash burns, or those due to hot gases and debris[19,34,36] and blast-induced fires.[18] Non-line-of-site thermal phenomena due to hot, dust-laden air propelled into structures by the blast wave can be a serious problem with nuclear explosives, but are probably of little significance for conventional materials. However, detonatable gases and cryogenic mixtures may well include serious burns as well as other blast effects depending upon the fuel ratios involved. Finally, under certain circumstances in confined spaces, toxic gases such as carbon monoxide and carbon dioxide, may contribute to the cause of blast-associated casualties.[3]

III. Problem Areas

Those special portions of environmental medicine and industrial safety related to biological blast effects include, as noted above, a variety of physical, biophysical, and biomedical parameters that deserve considerable attention.[28,32,34] Their definition, quantitation, and interrelations encompass the technical problems involved. Most are straightforward in concept. All are plagued by lack of data, some more than others. Many are formidable and each deserves wider appreciation by professional research and operating personnel.

A. Physically Oriented Problem Areas

To help emphasize the fact that blast-induced variations in the environment of interest biologically can occur in the open as well as in other inhabited locations, FIGURE 1 was prepared. Included also were additional physically oriented problem areas of note. Each will be discussed briefly below.

1. Free-Field Scaling

First, of course, is the energy source itself. In addition to the type of detonation involved and the factors governing the proportion of energy appearing as a TNT equivalent of yield, there are other uncertainties that determine events at locations of interest. Among them are explosive materials and design, range, burst conditions, ambient pressure, and weather. The blast scaling laws, appearing in various publications[18] and aided by tabular and mechanical devices,[42] allow one to predict, for specified conditions, blast parameters as functions of yield and range that occur in the open and over reasonably flat terrain. Such range-yield-effects relations give reasonable approximations to guide those who would deal with hazards to personnel, providing free-field exposures are the ones of interest.

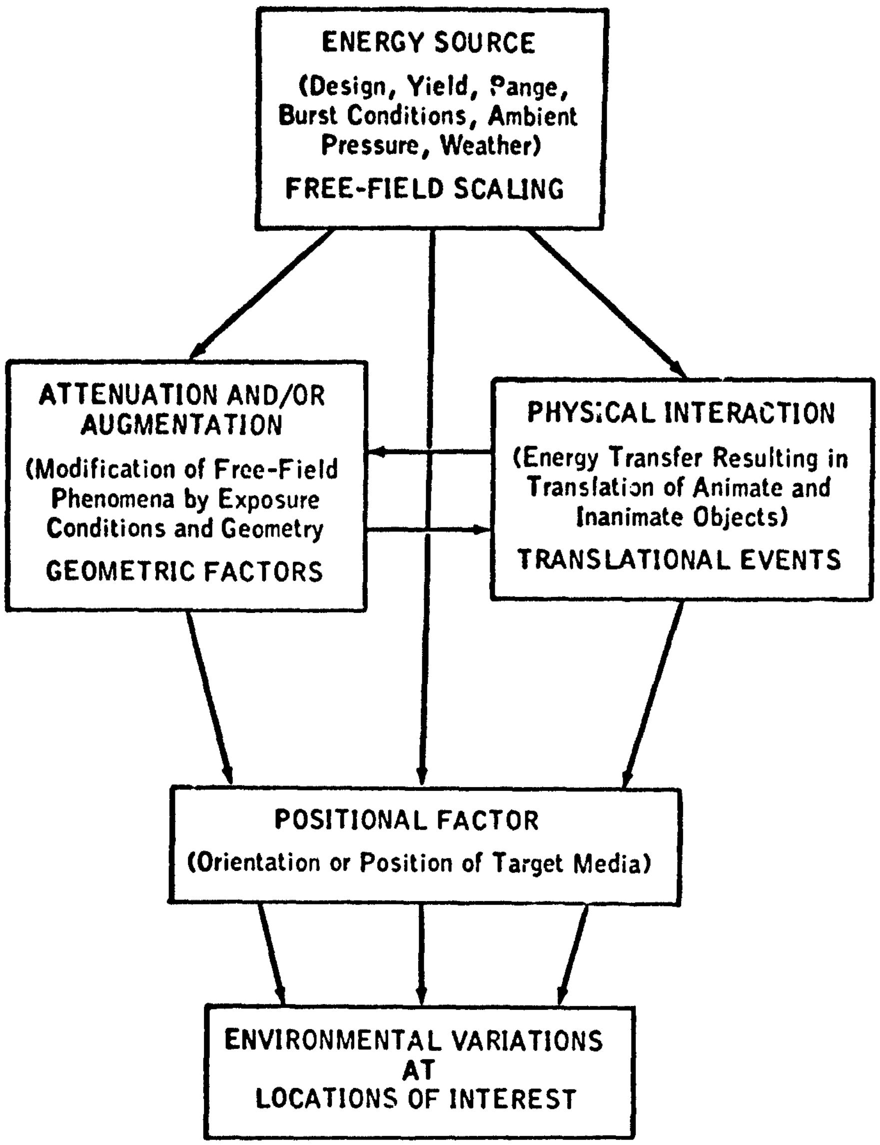

Figure 1. Physically Oriented Problem Areas

2. Geometric Factors

However, if inhabited areas are inside buildings or other above and below ground regions, geometric factors are likely to modify the free-field phenomena considerably; viz., conditions may be attenuated or augmented, but may remain unchanged.[19,43,44] Variations between maximal incident overpressures and those occurring inside open shelters may vary by factors of at least 2 to 3 in either direction and those interested are referred to a recent summary of full-scale field data for details.[36] Also, there are changes in the shape of the pressure-time pulse and alterations in the wind pattern that are much a function of the local geometric circumstances.

3. Translational Events

Whether exposure occurs in the open or inside a variety of open or partially open structures, significant transfer of energy to animate and inanimate objects may occur. As a consequence, translational events, involving whole-body displacement, free-field debris, window glass, other frangible materials, and even the stoutest building materials, ensue. Though these are responsive to range, yield, and the type of construction involved, the resulting hazard to personnel from missiles and decelerative impact is serious indeed. Though some progress has been made in translational scaling for objects as small as slivers of glass and as large as adult man[18,26,30,45]* energized by fairly typical wave forms, the situation is not satisfactory for atypical pressure pulses nor for a variety of exposure conditions which deform the wave pattern considerably.

4. Positional Factor**

The potential hazard to personnel is now known to be sensitive to orientation and position. This is patently true, for example, if exposure occurs inside buildings where face-on or back-on orientations in front of or well away from glazed windows can be relatively harmless or highly hazardous for comparable free-field conditions.

The operation of the positional factor for locations in the open is not so obvious, but recent experience in the laboratory indicates not only that primary blast tolerance varies significantly for side-on and head-on (or tail-on) exposures, but poses range-scaling problems that are not subject to straightforward solutions. Such relevant data will be presented elsewhere in these proceedings.+

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*See also the contribution of E. R. Fletcher et al., appearing as DASA-1859 and in the proceedings of the New York Academy of Sciences conference mentioned on page 3.

**Use of the phrase positional factor was suggested by Dr. Mathew G. Gibbons during discussions at the August meeting of the Subcommittee on Blast and Thermal Effects of the National Academy of Sciences Advisory Committee on Civil Defense.

+The reader is referred to the papers by Richmond et al. and Bowen et al. noted in the footnote on page 3.

5. General

Thus, it is clear that geometric and positional factors as well as translational events must be considered along with free-field scaling if one is to understand and quantitate the environmental variations that occur at different inhabited locations. In fact the local conditions of exposure and the position and orientation of biologic targets emerge as major determinants in assessing blast hazards. Indeed these matters may be as important as variations in yield by factors of from 2 to 10 depending upon the conditions delineated.

B. Biomedically Oriented Problem Areas

Those who develop biomedical criteria for assessing hazards from blast-induced environmental variations must also consider the problem areas noted in FIGURE 2. It is essential to work with the environmental challenge monitored very close to the location of exposure and develop quantitative relationships that relate various levels of the environmental challenge to graded degrees of biological response. To do this, a number of tasks must be completed more or less successfully.

1. "Loading" Forces

For example, more often than not it is necessary to search for and identify the biologically significant physical parameter or parameters. Subsequently one learns how reliably to reproduce and monitor the force or forces which "load" the target, after which experiments to determine effects as a function of the magnitude of the challenge can be designed and performed.

2. Biophysical Interaction

The detailed mechanisms at play during the transfer of energy to biologic media and how energy is dissipated by or within the living target are often as obscure as they are significant. At least this area of biophysical interaction, if fruitfully explored, can help identify factors of etiologic significance. Until these are forthcoming, no enlightened understanding of how and why injuries occur can be conceived.

3. Biological Response(s)

Relating stimulus to response quantitatively also requires identification and monitoring the critical biological consequence(s) of exposure. Herein it is helpful to call upon what is known of the major medical syndromes for single and combined stresses, but if the symptomatology is found lacking or inapplicable, one develops, through experiment, data that add new and appropriate dimensions to medicine.

As was noted in the discussion of primary blast in a previous paragraph, the hazardous nature of blast phenomena makes it necessary to rely heavily on animal studies. Thus, intraspecies findings and extrapolations play a vital role in estimating human tolerance to stress.

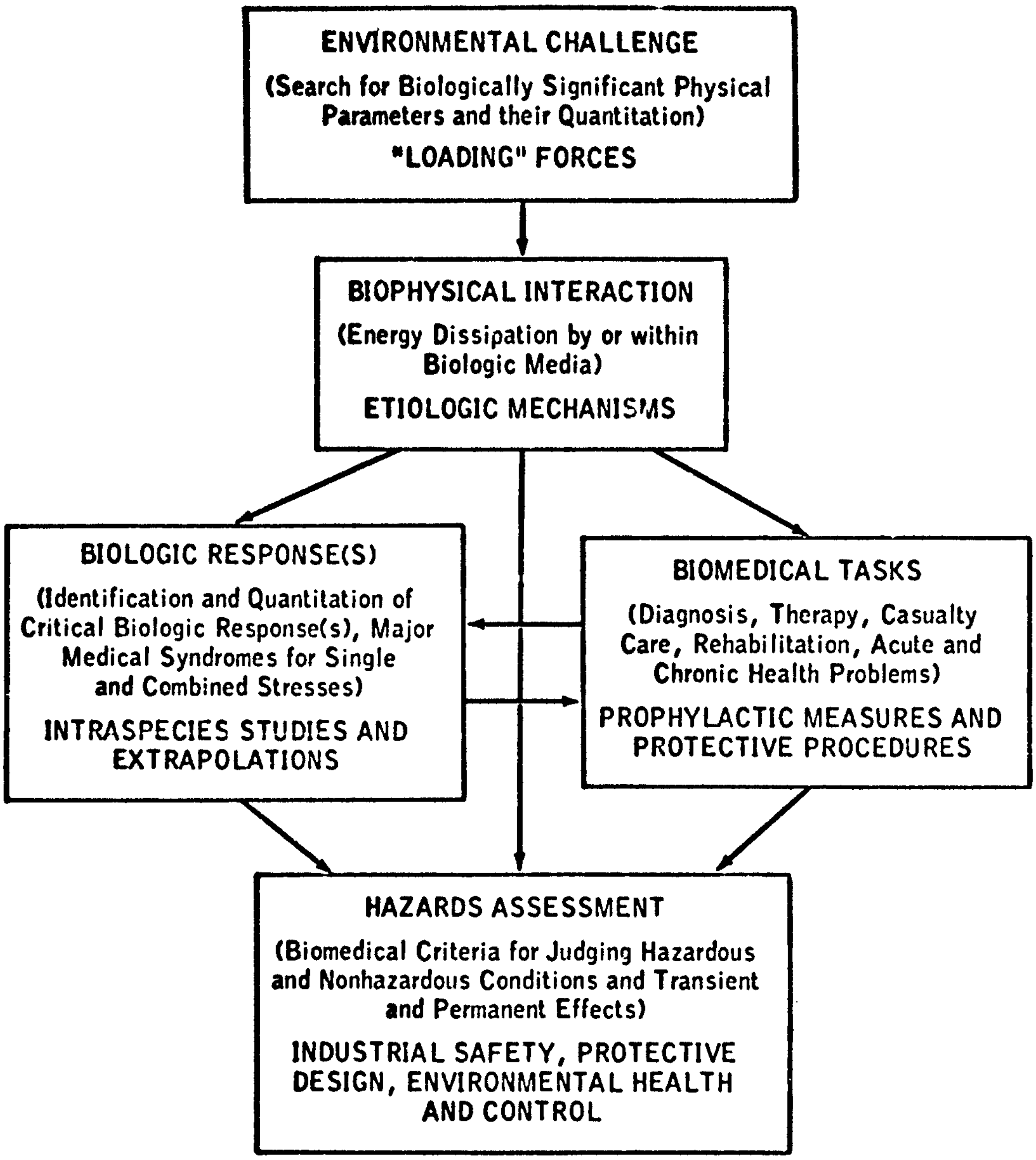

Figure 2. Biomedically Oriented Problem Areas

4. Biomedical Tasks

Similarly what is known about diagnosis, therapy, casualty care, rehabilitation, acute and chronic health problems, prophylactic measures and procedures is called to mind to help understand the significance of documented responses to environmental alterations. Here again, if in pursuing the problem at hand what is observed is both important and novel, more meaningful evaluations can be made on the basis of advances in understanding.

5. Hazards Assessment

Besides contributing information to improve medical recognition and handling of blast casualties, the experimental and theoretical studies of biological blast effects have at least two other end products. The first concerns the formulation of biomedical criteria for assessing hazards. This involves learning in turn what level of a given environmental variation can be regarded as "safe," or at least seldom associated with more than a few casualties; what levels are associated with performance decrement, with frank casualties, with reversible and irreversible sequelae, and with low, intermediate, and "high" levels of lethality.

The second end product concerns contributions to the important matters of industrial safety, protective design, and environmental health and control. In certain instances for example, this may go so far as to influence the formulation of building codes for certain kinds of structures and the design and layout of harbors handling significant quantities of high explosives and other detonatable materials. Also, the information stemming from blast biology programs is useful in updating or originating a variety of safety manuals for industry, range-safety officers at satellite and missile-launch sites, and delineating standard procedures for storing, shipping, handling and using the variety of explosives now at hand as well as those that will become available in the future.

6. General

In summary, those who would advance the understanding of blast effects, including the challenge to man, must work to complete the quantitative fabric needed to encompass and interrelate adequately all the problem areas noted in FIGURES 1 and 2. This will require the best efforts of individuals trained in the physical and biological sciences, for there are many complexities involved and currently much needed information simply is not at hand. Though a great deal more now is known than in the past, a continued effort both on the conceptual and empirical frontier must go forward to refine criteria for hazards assessment on the one hand and on the other to relate these properly to the explosive source, keeping in mind the prime significance of the blast-induced environmental variations that occur locally at the exposure site.

IV. Discussion

Ideally and so far as is currently possible, biomedical criteria for assessing blast hazards need be simple, accurate, practical and broadly usable by all individuals concerned, be they for instance physicists or biologists, biophysicists or physicians, architects or engineers. In reality such a requirement can be met eventually if all work to achieve a functional interaction from which emanates an awareness of the problem areas of primary concern to each discipline.

For example, biomedical talent working with the missile hazard need information concerning the mass, velocity and character of materials energized by explosions including crater ejecta, their discrete size, trajectories and range to guide the design of biological experiments and to help assess the relative significance of the several blast-induced events as they vary with yield, range and exposure geometry. Similarly, industrial safety personnel and architects and engineers responsible for protective design should have biomedical criteria that are both precise and usable.

It is one thing, to cite another example, to say that under no circumstances should the winds allowed inside a structure be of such velocity and duration as to impart a velocity of 10 or more ft/sec to an exposed individual, and quite another to accompany such a statement with critical data encompassing the special aerodynamics involved including the orifice coefficients, volumes and other factors needed to handle geometric factors, as well as the velocity-mass-distance-time relationships as they vary for the acceleration coefficients applicable to man's different exposure positions.

Likewise a primary-blast criteria stating that the pattern of overpressure at an inhabited location should be in magnitude and duration less than required to produce within 3 to 5 msec a maximal intrathoracic pressure peaking to some multiple of the ambient might very well be quite correct, but would hardly be usable by an architect-engineer designing a protective structure. Such criteria could become practicable _if_ the architect-engineer were given the appropriate intra-species scaling data relating external "load" to internal response and _if_ he also knew how to express the pressure variations at the location of exposure as some appropriate ratio of those emanating from the explosive source; viz., he must handle the free-field scaling problem plus the alterations attributable to the geometric and positional factors should they prove critically applicable.

These few examples will to some extent at least serve to make the reader aware that formulating realistic criteria as well as their application to various defined conditions of exposure are far from simple, often being to the contrary quite complex. In fact the required complete data are simply not at hand. As a consequence, the fomulation of firm criteria and rules for their application in a variety of conditions cannot be accomplished satisfactorily, the "state of the art" being what it is.

However, it has been feasible for some time to formulate tentative biomedical criteria as was alluded to in the introduction. Indeed from time to time, the advent of new findings and advances in understanding have allowed earlier criteria to be updated and extended

Even so, the criteria currently at hand remain both tentative and incomplete. In spite of often being the product of best estimates and frequently far from refined, they have proven surprisingly useful in a number of ways. Not least in this regard have been a clear-cut realization of deficiencies on a broad front and the concomitant stimulus to gain knowledge and expertise to the end that better and more complete biomedical criteria can be formalized and can be applied with more assurance to a wide spectrum of exposure conditions.

With this spirit of progress in mind and with the hope that this conference* might contribute new ideas and data, currently available tentative criteria are reproduced here in TABLES 1 through 4 for both direct and indirect blast effects.** It could be that the criteria tabulated will withstand current scrutiny and for awhile remain unchanged. More likely there will be differences of opinion more or less serious among knowledgeable individuals. Perhaps there will be areas of agreement develop such as for threshold conditions; i.e., those environmental variations that are just "safe," but which if exceeded by a little or by very much represent mild and grave hazards, respectively.

Be these contingencies as they may, the reproduction here of tentative biomedical criteria for assessing blast hazards makes them available on the one hand for those who, lacking something better, will use them, keeping pertinent limitations in mind, and on the other hand for those who, desiring something better, will work to improve them by implementing the theoretical and empirical studies required to produce new data to gain fundamental advances in technology.

V. Summary

Following a brief introduction, the scope of blast biology was outlined. Included were: direct (primary) effects due to blast-induced variations in environmental pressure; indirect effects due to the impact of blast-energized missiles (secondary effects), indirect effects occurring as a consequence of whole-body displacement (tertiary effects), and other indirect effects included in a miscellaneous category.

Physically and biomedically oriented problem areas of concern to those who would formulate and utilize biomedical criteria for assessing blast hazards were identified and described.

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*See Preface.

**For a more complete and fairly recent presentation of tentative biomedical criteria and a summary of data from which they were derived, the reader is referred to reference 36.

TABLE 1

TENTATIVE BIOMEDICAL CRITERIA FOR DIRECT (PRIMARY) BLAST EFFECTS IN YOUNG ADULTS APPLICABLE TO "FAST"-RISING AIR BLAST WAVES OF THE INDICATED DURATIONS OCCURRING AT SEA LEVEL (14.7 PSI)

Over-pressure Duration Msec	Maximum Effective Overpressures* for Lethality in Psi			
	For 70-kg Mammal	For Young Adult Humans		
	50 Per Cent	Near Threshold	50 Per Cent	100 Per Cent
2	321	195-272	272-397	397-528
3	184	112-156	156-217	217-302
5	118	72-100	100-139	139-194
10	84.5	51- 72	72-100	100-139
20	71.5	43- 61	61- 85	85-118
30	67.6	41- 57	57- 80	80-111
60	64.0	39- 54	54- 76	76-105
400	61.0	37- 52	52- 72	72-100

Data from Richmond et al. and Bowen et al. appearing elsewhere (see footnote on page 3) and from CEX-65.4.[36]

*The tabulated maximum effective overpressures may be (a) the maximum reflected pressures for exposures with the thorax against a reflecting surface; (b) the maximal incident plus the maximal dynamic pressures for free-stream exposures side-on at 90 degrees to the advancing pulse; (c) the maximal incident overpressures for free-stream exposures end-on to the direction of travel of the blast wave.

NOTE:

1. The maximum effective overpressures may be associated with different incident overpressures depending upon the position and orientation at exposure. For examples, note the data in TABLE 2 for "fast"-rising overpressures of 3- and 400-msec duration.

2. Survival tolerance may be greater by about factors of two or five for pressure pulses reaching their maximum in two "fast"-rising steps over 3 to 5 msec or in a smooth manner over 30 msec or greater, respectively.

TABLE 2

TENTATIVE CRITERIA FOR DIRECT (PRIMARY) BLAST EFFECTS IN YOUNG ADULTS APPLICABLE TO "FAST"-RISING, "SHORT"- AND "LONG"-DURATION OVERPRESSURE IN AIR

AMBIENT PRESSURE: 14.7 PSI

Critical Organ or Event	Overpressures in psi as indicated for different pulse durations					
	3-msec Duration			400-msec Duration		
	P_e	P_{ir}	P_{if}	P_e	P_{ir}	P_{if}
Eardrum Rupture:						
Threshold	5	2.3		5	2.3	
50 per cent	15-20	6-8		15-20	6-8	
Lung Damage:						
Threshold	37-49	14-17	25-31	12-15	5-6	10-12
Severe	98 and above	29	53	37 and above	14	25
Lethality:						
Threshold	112-156	33-42	59-76	37-52	14-18	25-33
50 per cent	156-217	42-54	76-98	52-72	18-23	33-42
Near 100 per cent	217-302	54-69	98-127	72-100	23-30	42-54

P_e: Maximum effective overpressure, which may be

(a) the maximum reflected overpressure if the subject is against a reflecting surface,

(b) the incident maximum overpressure plus the associated maximum dynamic pressure for free-stream exposure if the long axis of the subject is perpendicular to the direction of travel of the blast wave,

(c) the incident maximal overpressure for free-stream exposure if the long axis of the subject is parallel to the direction of travel of the blast wave.

P_{ir}: The incident maximum overpressure, which would reflect at normal incidence to the indicated maximum effective overpressure, P_e.

P_{if}: The incident maximum overpressure, which when added to the associated maximum dynamic pressure results in a total overpressure equal to the indicated maximum effective overpressure, P_e.

Data from Zalewski;[47] CEX-65.4;[36] Hirsch, F. G. (DASA-1858); Richmond et al.; and Bowen et al. (see footnote on page 3).

TABLE 3

TENTATIVE CRITERIA FOR INDIRECT BLAST EFFECTS INVOLVING SECONDARY MISSILES
(Reproduced from CEX-65.4[36])

Kind of Missile	Critical Organ or Event	Related Impact Velocity ft/sec
Nonpenetrating 10-lb object	Cerebral Concussion:*	
	Mostly "safe"	10
	Threshold	15
	Skull Fracture:*	
	Mostly "safe"	10
	Threshold	15
	Near 100 per cent	23
Penetrating 10-gm glass fragments	Skin Laceration:+	
	Threshold	50
	Serious Wounds:+	
	Threshold	100
	50 per cent	180
	Near 100 per cent	300

*Data from Lissner and Evans;[48] Zuckerman and Black;[49] Gurdjian, Webster and Lissner.[50]

+Data from AECU-3350,[16] WT-1470,[51] and CEX-58.8;[52] figures represent impact velocities with unclothed skin. A serious wound arbitrarily defined as a laceration of the skin with missile penetration into the tissues to depth of 10 mm or more.

TABLE 4

TENTATIVE CRITERIA FOR INDIRECT (TERTIARY) BLAST EFFECTS INVOLVING IMPACT

(Reproduced from CEX-65.4[36])

Condition Critical Organ or Event	Related Impact Velocity ft/sec
tanding Stiff-Legged Impact*	
Mostly "safe"	
No significant effect	<8 (?)
Severe discomfort	8 - 10
Injury	
Threshold	10 - 12
Fracture threshold (heels, feet and legs)	13 - 16
eated Impact*	
Mostly "safe"	
No effect	<8 (?)
Severe discomfort	8 - 14
Injury	
Threshold	15 - 26
ikull Fracture†	
Mostly "safe"	10
Threshold	13
50 per cent	18
Near 100 per cent	23
Total Body Impact†	
Mostly "safe"	10
Lethality threshold	20
Lethality 50 per cent	26
Lethality near 100 per cent	30

*Data from Draeger, Barr, Dunbar, Sager, Shelesnyak;[53] Black, Christopherson and Zuckerman;[54] Swearingen, McFadden, Garner and Blethrow;[23] Hirsch;[33] and Eiband.[55]

+Data from Gurdjian, Webster and Lissner;[50] Zuckerman and Black.[49]

†Data from DASA 1245.[25]

On the physical side these included uncertainties regarding the explosive source and free-field scaling; the attenuation and augmentation of physical parameters associated with geometric factors germane to various exposure conditions, physical interaction and the energy transfer associated with translational events encompassing animate as well as inanimate objects; and the contributions of positional and orientation factors. An understanding of appropriate combinations of the problem areas mentioned is essential to determine the environmental variations at locations of interest.

The biomedically oriented problem areas included: a search for the biologically significant physical parameters and their use to define "loading" forces quantitatively; the energy dissipation involved in biophysical interactions and the related etiologic mechanism at play: identification and quantitation of critical biological responses among a variety of mammalian species; a variety of acute and chronic health problems concerned with diagnosis, therapy, casualty care, rehabilitation and prophylactic measures and protective procedures; and finally the formulation of biomedical criteria for assessing various levels of blast hazards along with their use and application in industrial safety, protective design and environmental health and control.

Attention was called to the lack of data required to interrelate quantitatively the physical and the biological factors outlined and the need was emphasized for collaboration among personnel trained in the physical and biological sciences to formulate refined biomedical criteria for assessing blast hazards in man and to apply the criteria properly to various conditions of exposure, either in the "open" or in a variety of above and below ground structures be these either "open" or "closed."

Some of the characteristics of acceptable biomedical criteria were discussed. Tentative though incomplete criteria applicable to direct and indirect blast effects were presented in tabular form as examples of what has been useful in helping assess blast hazards and as a means of stimulating interested individuals to contribute ideas and data to update, improve and extend the criteria as well as to refine their application to blast-induced environmental variations of note occurring in any one of the wide spectrum of possible exposure conditions wherein man or equipment might be situated.

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A few introductory remarks ~~were~~ followed by a brief discussion of the nature of hazards from air blast noting those due (a) directly to variations in pressure and (b) indirectly to the impact of penetrating and nonpenetrating, blast-energized missiles and the consequences of whole body displacement due to blast-induced winds or ground shock. The need for developing biomedical criteria based upon critical and measurable biological responses following exposure to significant and monitorable physical parameters ~~was~~ discussed in relation to hazards assessment. Also the multifaceted problem of tying up such information with blast-induced variations in the environment that occur free-field and under various conditions of exposure ~~was~~ noted and emphasized.

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